

The Instrumentation Frontier

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Instrumentation Frontier Conveners



*DPF Community Summer Study
"Snowmass on the Mississippi"
Minneapolis, July 29 - August 6, 2013*

A Little Bit of History

Instrumentation is the enabler of science, both pure and applied

- In 1974 Bill Willis and Veljko Radeka studied noble liquids for the first time at Columbia and BNL for calorimetry

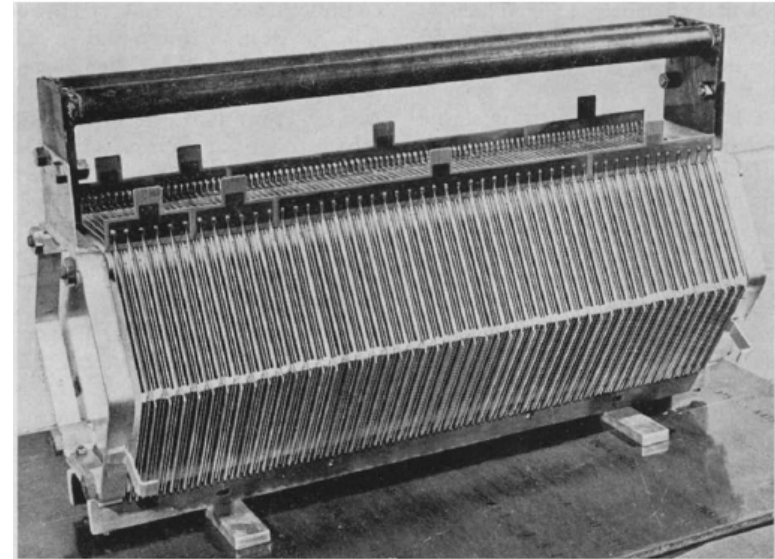
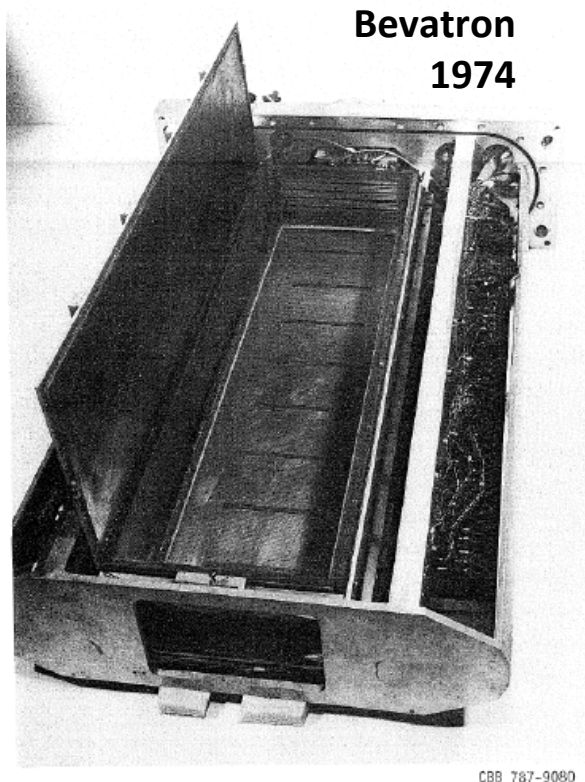
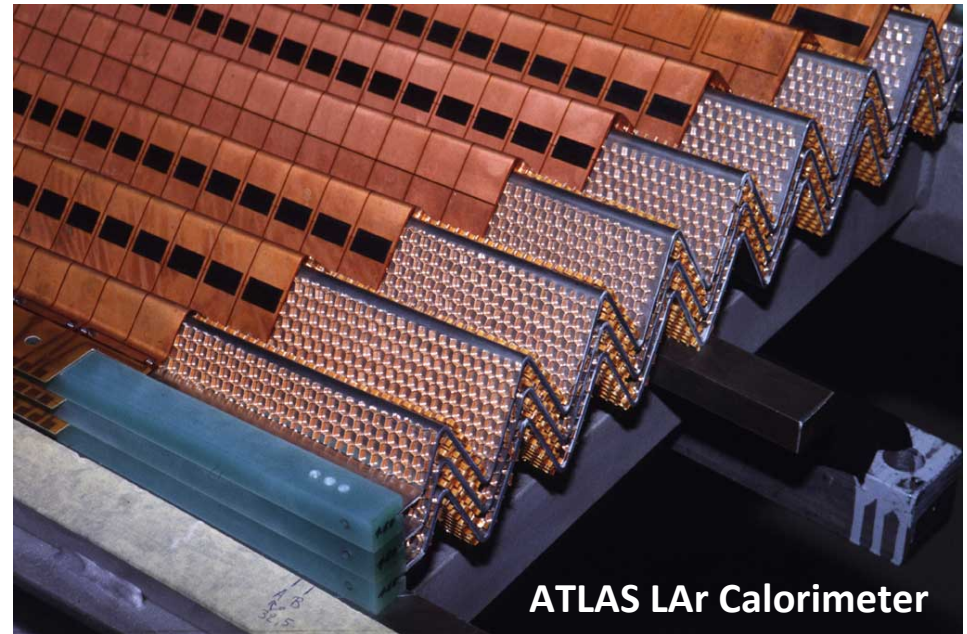


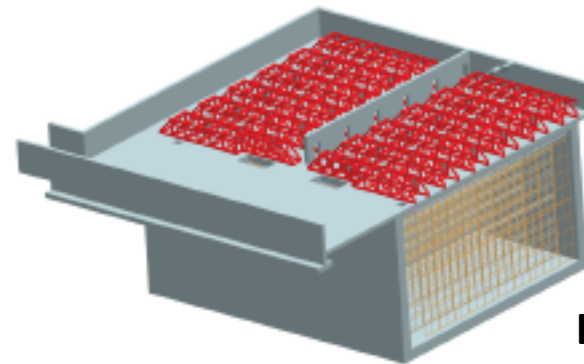
Fig. 10. Large test chamber with 200 steel plates, 1.5 mm thick, with 2.0 mm gaps.

- In 1976 Dave Nygren invented the Time Projection Chamber at Berkeley

The Engines of Current and Planned Experiments



ATLAS LAr Calorimeter

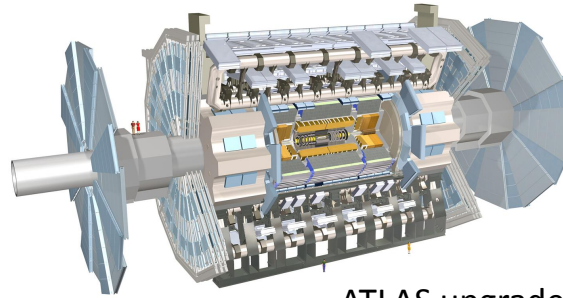


LAr TPC LBNE

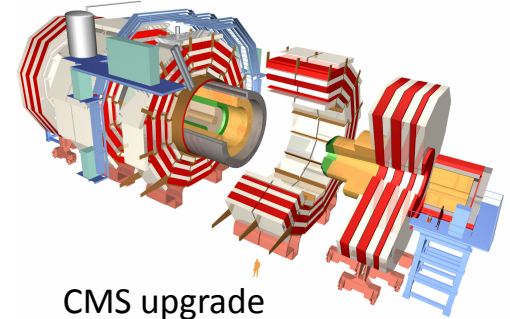
The seeds sown long ago in the US



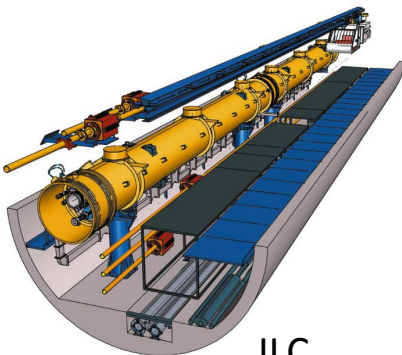
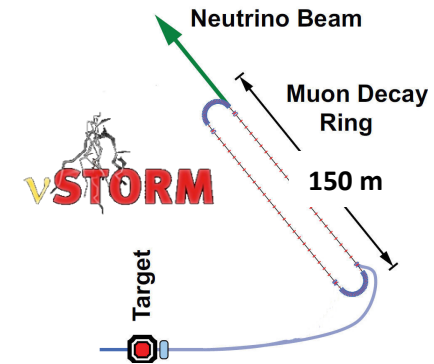
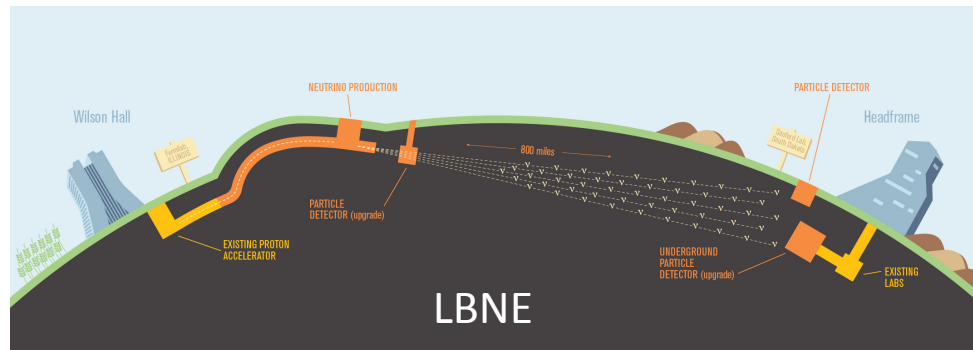
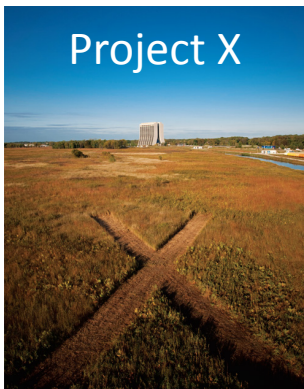
Big Ambitions ...



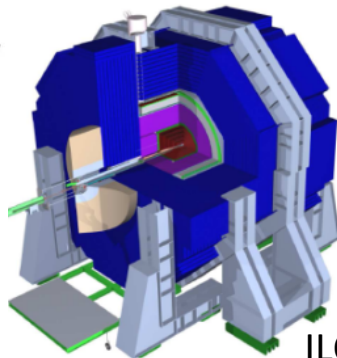
ATLAS upgrade



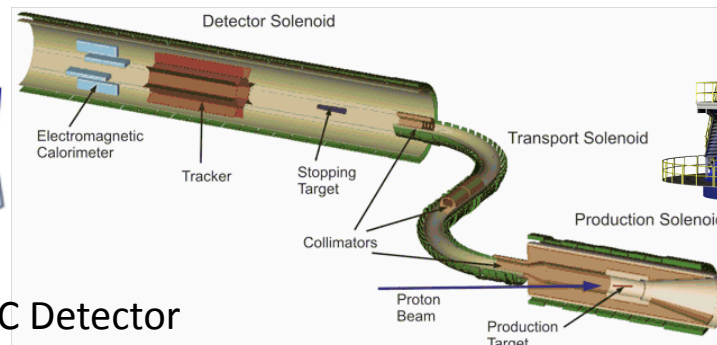
CMS upgrade



ILC



ILC Detector



Mu2e



LSST

Big Questions ...



But the Real Big Question ...



The Real Big Question

■ How can we fit our ambitions within our budget ?

- Carry out a flagship domestic program, and have a leadership role in off-shore projects
- Invest in the future such that the US is again recognized as a leader in high energy physics



- The View from, and Role of, the Instrumentation Frontier following the guidelines of the director of OHEP:
 - “... from the study process a community consensus on a ‘situation analysis’ for each major subsection of our field. What are our current strengths and capabilities, and what are the opportunities we face.”
 - “The ‘situation analysis’ can be accompanied by a ‘decision tree’ that summarizes a range of future options.”

THE SITUATION ROOM

Pre-Snowmass Meetings



Ron

Marcel

Ian

Ed

Abe

Ulrich

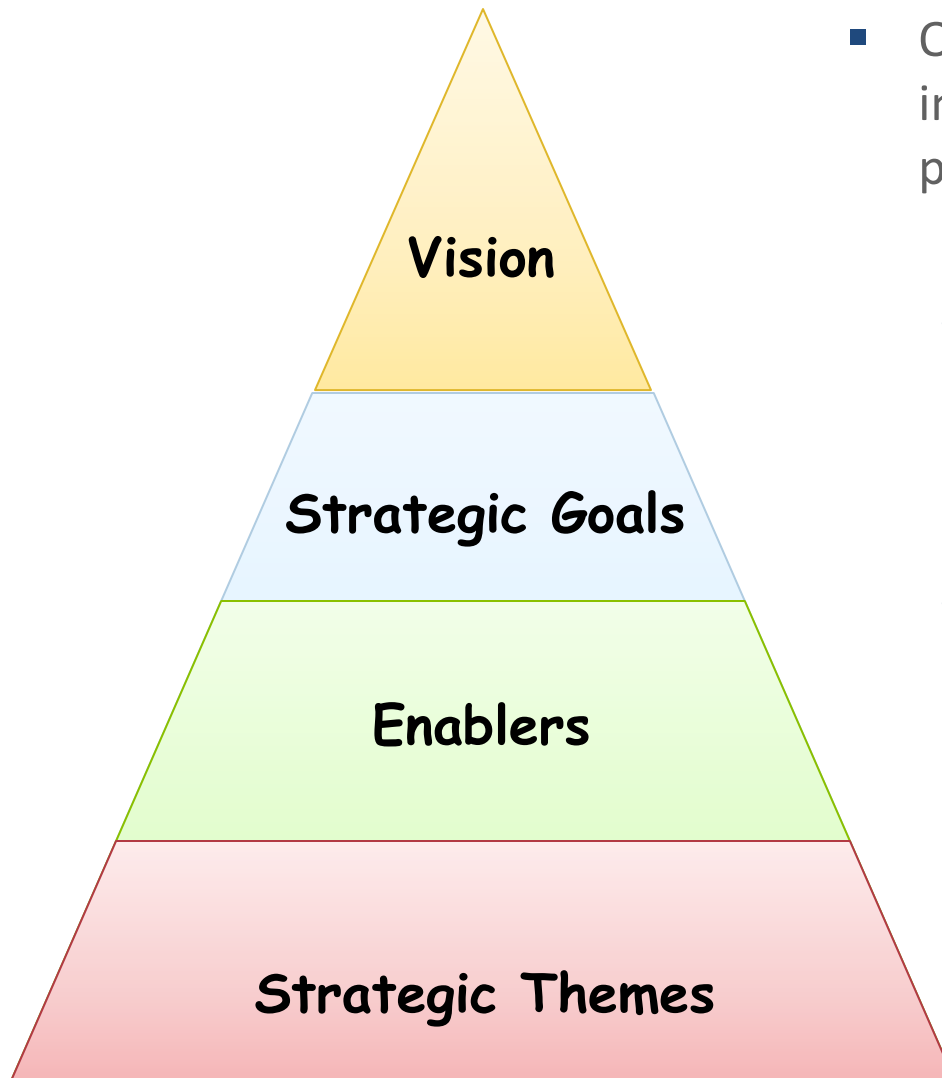
David

Howard

Marina

Jim

Instrumentation Frontier



- Our vision is for the US to have an instrumentation program for particle physics that:
 - Enables the US to maintain a scientific leadership position in a broad, global, experimental program
 - Develops new detection capabilities that provides for cutting edge contributions to a world program

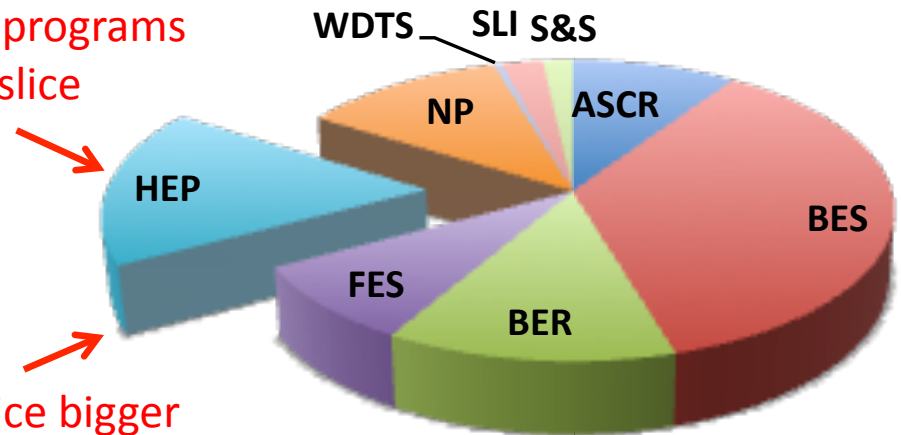


Strategic Goals

- Develop more cost-effective technologies with increased reach
1. Develop balanced Instrumentation, based on our strengths, aligned with research priorities
 2. Balanced funding level between projects and R&D and a program with appropriate “portfolio of risk”
 3. Develop process for integrating universities, national laboratories, other branches of science and industry
 4. Create opportunities for careers in HEP instrumentation
 5. Identify opportunities for technology transfer and collaboration with other sciences

Fit more programs into this slice

Make slice bigger



Office of Science 2013 Budget

Why an Instrumentation Program ?

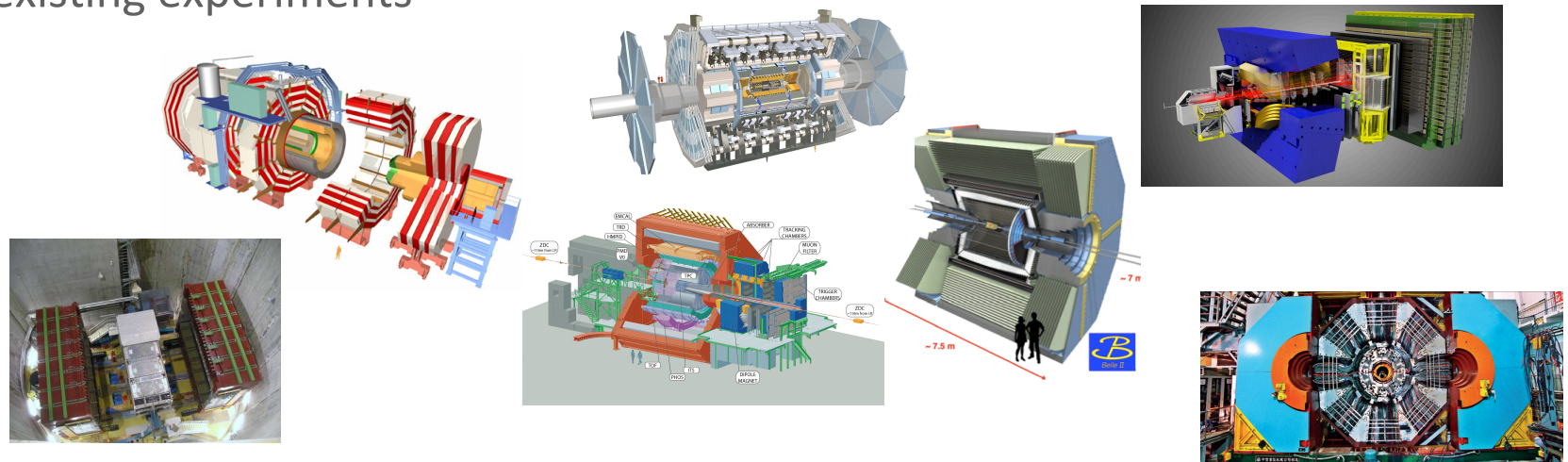
- The old paradigm for detector development no longer works
- During economic hard times there is enormous pressure on “discretionary” funding
- Support for new instrumentation development is an investment in the future
- Paradigm altering advances are happening in other branches of science, which hold the potential to lead to transformational new technologies for HEP
- This arguably could not be a more critical time to strategically invest in detector R&D.
- It is imperative that the field takes advantage of these opportunities,
- Supported by the administration (PCAST report)

The opportunity for innovation is tremendous !



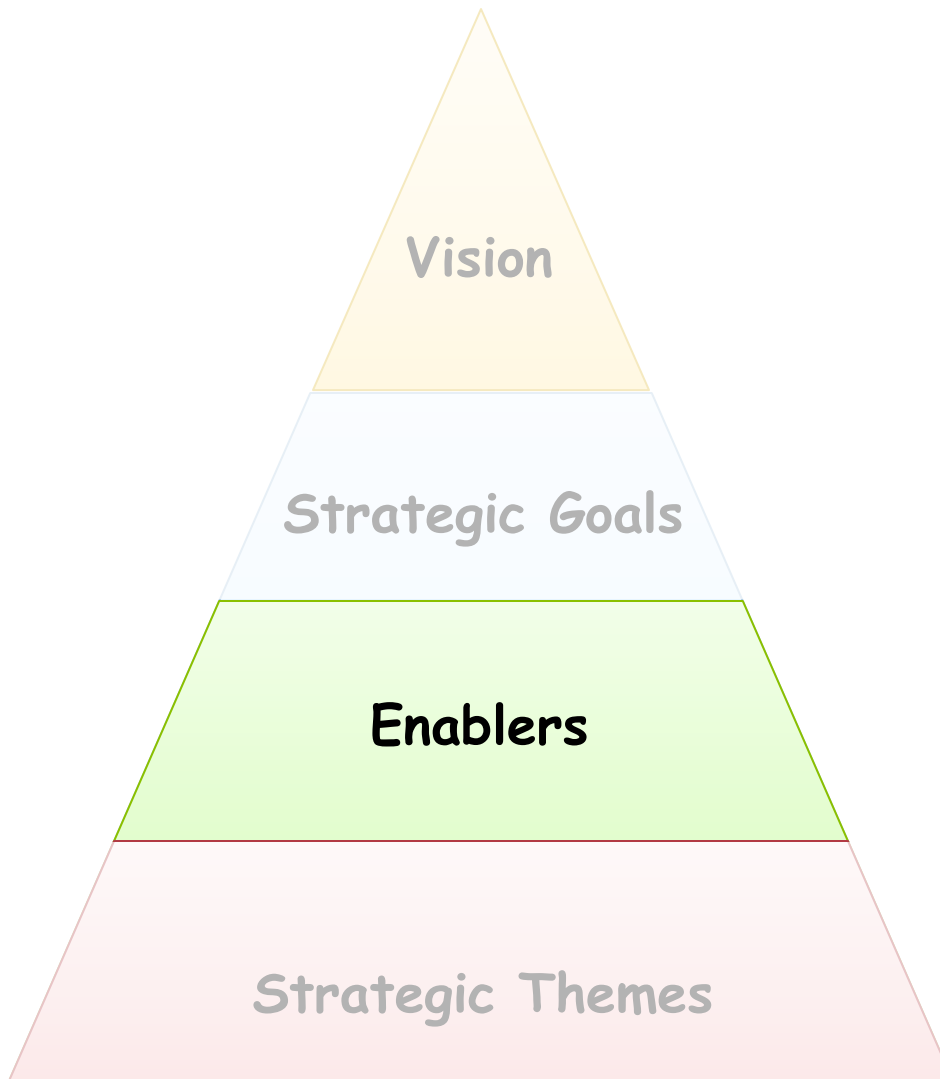
Current R&D

- R&D is more and more driven by present or incoming experiments with their limiting constraints: schedule and risk
- 2012 European survey shows that 85% of detectors R&D is done within existing experiments



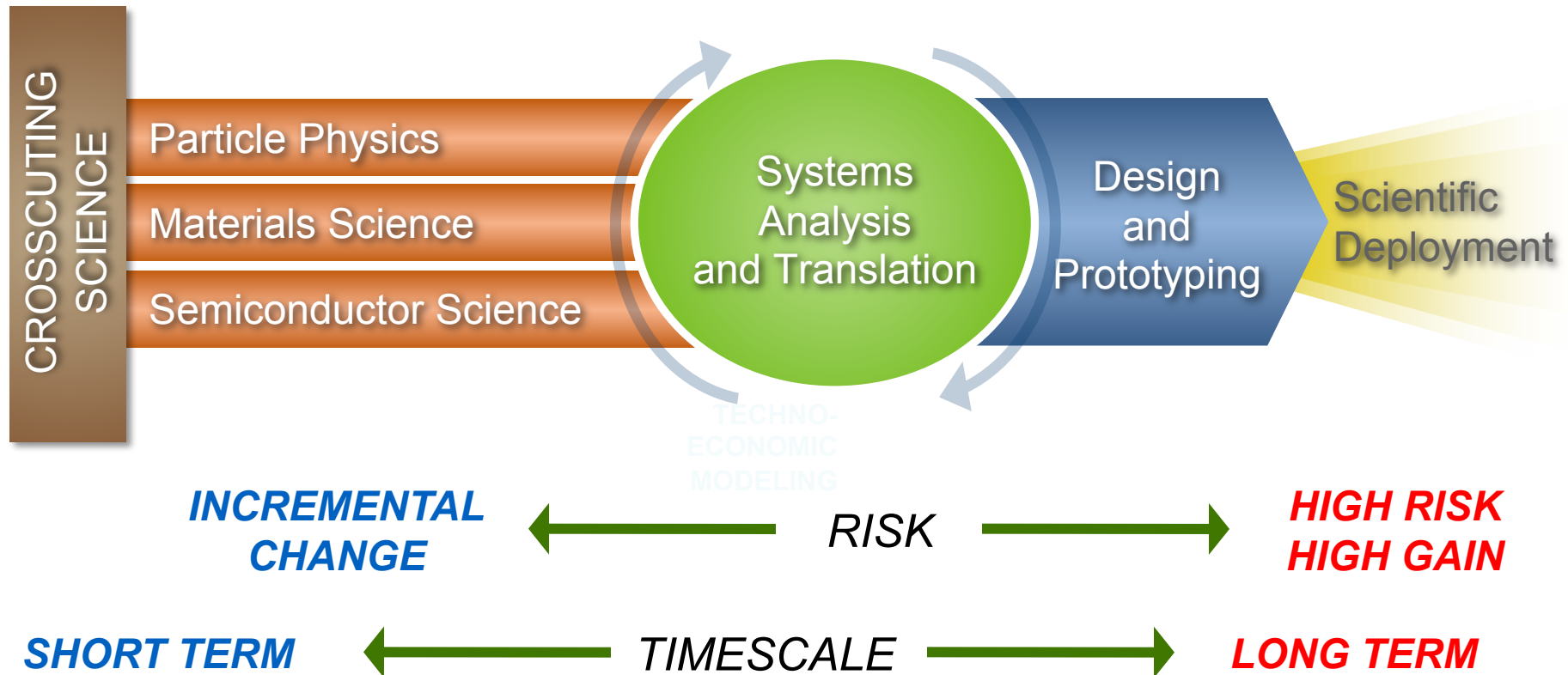
- Even if the experiment (upgrade) is >10 years away, implementation tends to be evolutionary
- This has not been the case before; Is there a risk to limit emerging technologies?

Instrumentation Frontier



Voice of Instrumentation

- Advocate of instrumentation to articulate, promote, coordinate and implement the strategic goals for instrumentation: CPAD



CPAD

Coordinating Panel for Advanced Detectors

CPAD appointed in 2012
<http://www.hep.anl.gov/cpad/>

Innovation Through Partnerships

Materials
Science

Nano
Technology

Photonics

Electrical
Engineering

HEP

National Laboratories



Academia

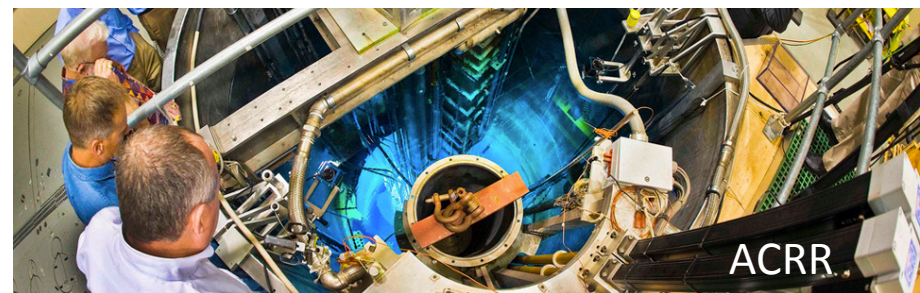
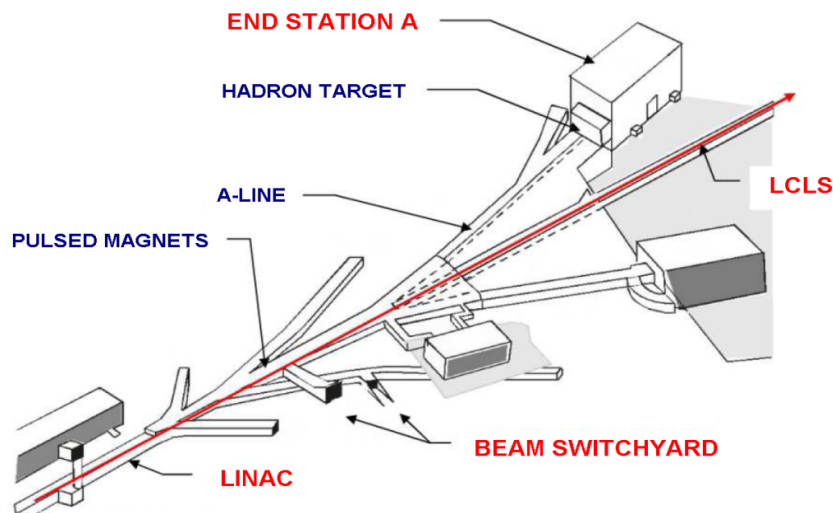
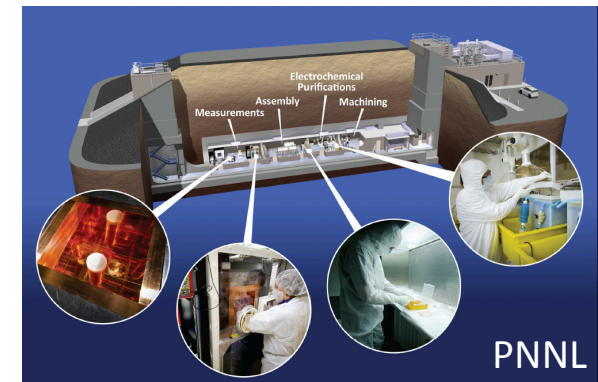


Industry



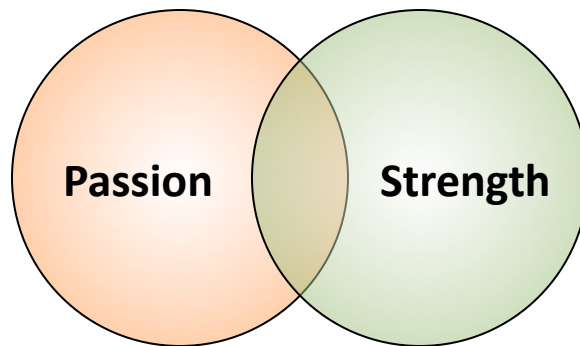
Balanced Portfolio of Risk

- Program needs a balance between evolutionary and revolutionary detector R&D and appropriate level of 'generic' project related detector R&D
- Risks get larger as the scale of experiments and collaborations grow
- **Program to be structured to allow for excellent mistakes**
- **Innovation distinguishes between a leader and a follower**
- Supported by facilities at labs and universities



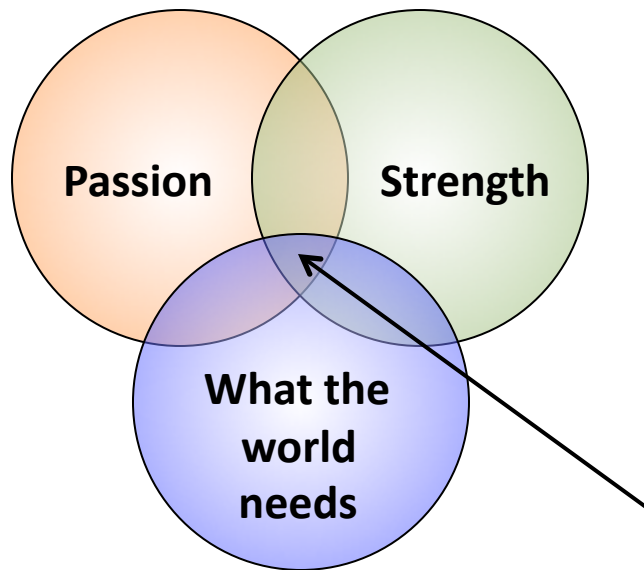
Community

- Key enabler is the (young) physicists
 - Need to provide the challenges
 - Need to provide a career path



Community

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 - Need to provide the challenges
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Has to be part of our mission !

- Use our strengths to do what we love ...
- **And** do work worth paying for that solves a problem or helps others
- Instrumentation is the obvious path to address this and provides a means to increase the overall HEP budget



Funding Balance

- What is the right balance between project funding and support for generic detector development ?
- Would you be willing to invest, say, a penny on the dollar in the development of a potentially transformative technology even if it does not directly benefit your project ?



You !

- Note: question not for Snowmass nor P50, but we would like to hear your opinion

Grand Challenges

- Suggest to enhance the detector development program with periodic competitive call for “Grand Challenges”:
 - To address key technological issues that currently limit science reach
 - Adopt innovative approach that could prove transformational if successful
 - Has emphasis on multi-disciplinary approach
 - Builds on close collaboration with universities and national laboratories given the cross-disciplinary aspect of the research
 - Be a periodically reviewed longer term program at adequate funding level
- Make instrumentation a most attractive setting which provides a challenging environment, to develop, recruit, and retain the best and brightest throughout the world



Take a Chance !



**It's what HEP is
founded on**

**It's an investment
in the future !**

Instrumentation Frontier



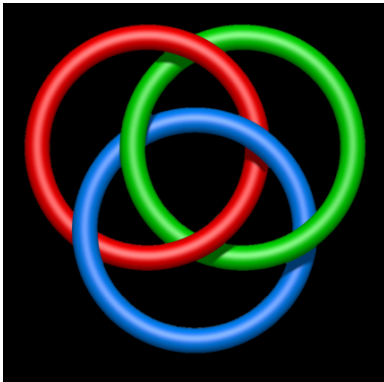
Levels of Instrumentation Development



- At the lowest level is the instrumentation development that takes place within the individual experiments; R&D is very much project driven and project funded;

Not the main focus of the Instrumentation Frontier

Levels of Instrumentation Development



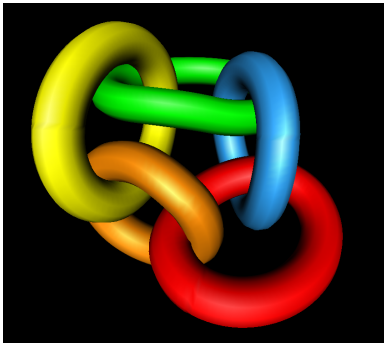
- At the intermediate level is the R&D that tries to identify the link between the various projects (like the Borromean Rings); R&D is more long term and adds value to all projects



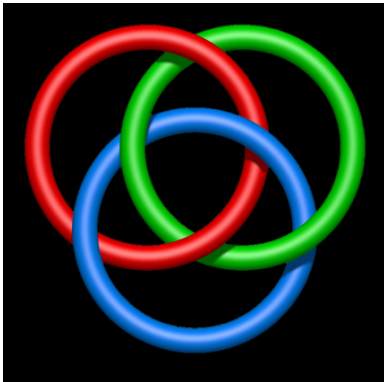
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Not the main focus of the Instrumentation Frontier

Levels of Instrumentation Development



- At the highest level is the instrumentation development that has added value to the field as a whole; R&D is long term and is aimed at being truly transformational



- At the intermediate level is the R&D that tries to identify the link between the various projects (like the Borromean Rings); R&D is more long term and adds value to all projects

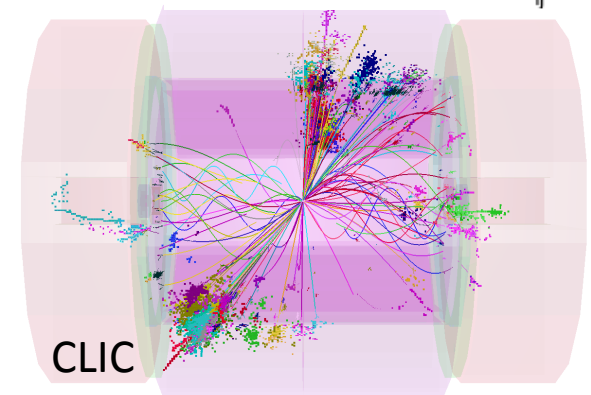
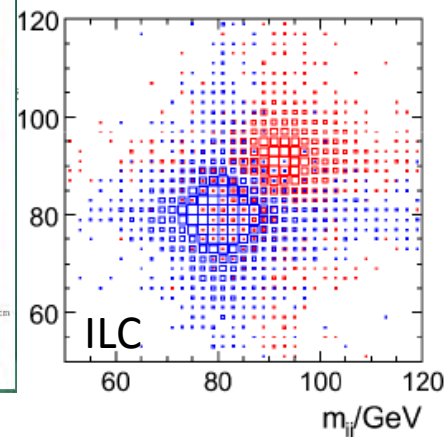
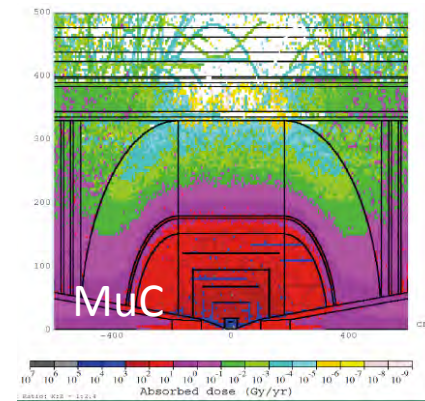
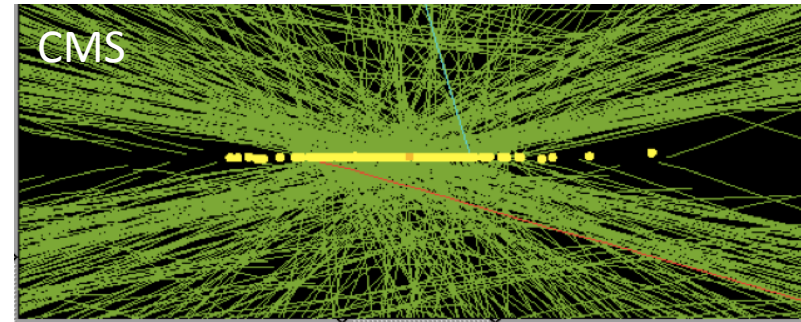


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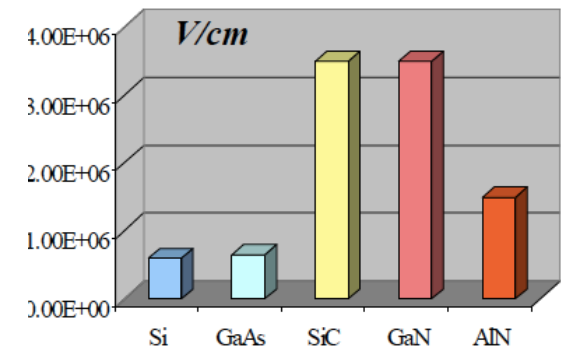
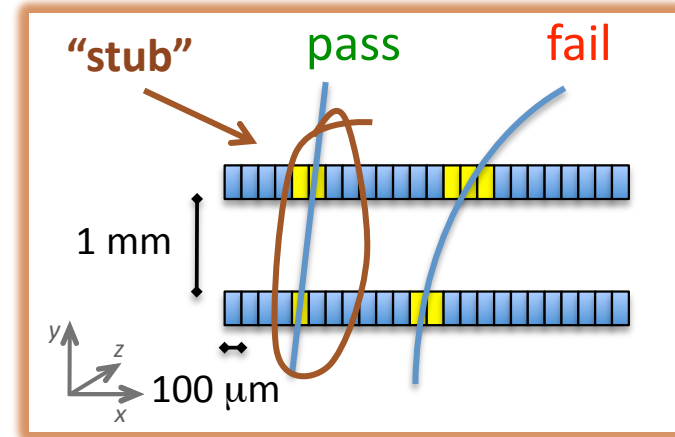
Energy Frontier Challenges

- LHC Upgrades
 - Huge data rates, Pileup
 - Increase rejection power of trigger system
 - Low power, high bandwidth links
 - Pixelization
 - Precision timing
- Linear Colliders (ILC/CLIC)
 - To separate hadronic W/Z decays superior calorimeter resolution
 - High pixelization
 - Low mass and low power detectors
 - Precise timing for short bunch spacing (CLIC)
- Muon Collider
 - High Backgrounds
 - Precise timing
 - Radiation tolerance



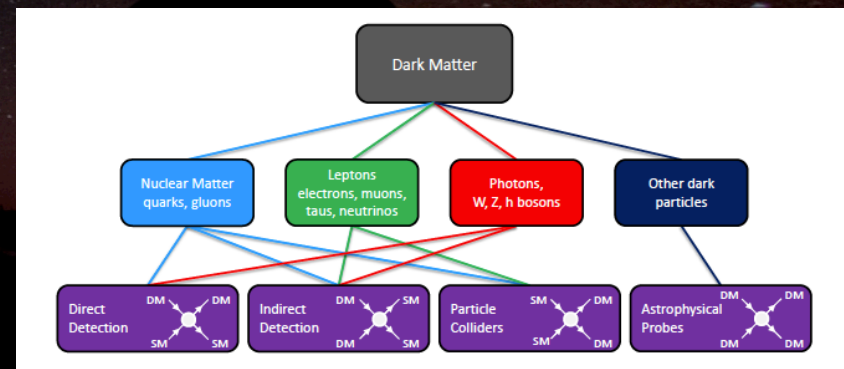
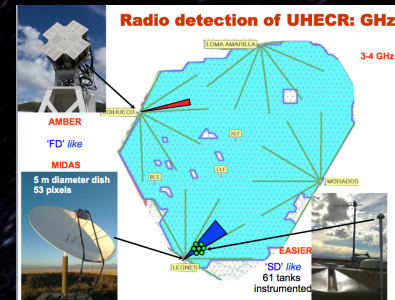
Energy Frontier Common Technologies

- Pixelization
 - New interconnect technologies
 - Low power data transmission
 - Technologies for 3D electronics
- Data transmission
 - Low power optical interconnects
 - Wireless transmission
 - Waveform digitization
- Speed
 - Faster sensor technologies
 - Low power, fast electronics
- Calorimetry
 - Imaging calorimetry
 - Radiation tolerant crystal calorimetry
- Mechanics and Power
 - Low power signaling



Cosmic Frontier Challenges

- UHE-CR
 - Low rates at high energy
 - R&D: Radio Detection, detection of air shower from space
- UHE-neutrinos
 - R&D: Need development of new antennas, low noise amplifiers for detection of Cherenkov radio emission
- Gamma rays
 - R&D: Cherenkov and water tank arrays, Low-cost photosensors/low-power digitizers
 - Distributed timing across large arrays
- Dark Energy
- Dark Matter
 - R&D path: Low-resolution spectroscopy and spectroscopic capability to wide field optical surveys
- CMB
 - R&D path towards readout of large cryogenic multi-choic arrays



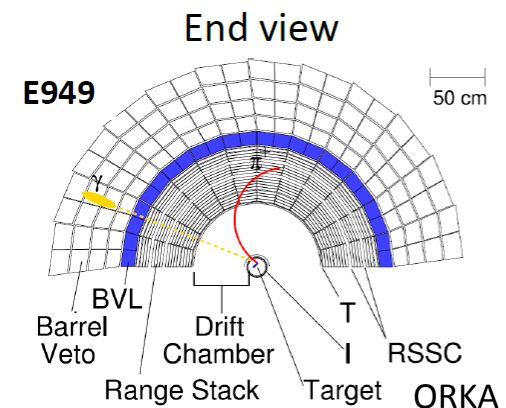
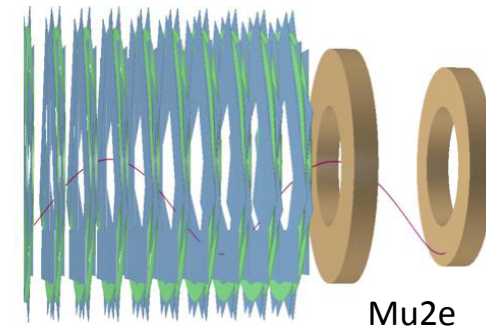
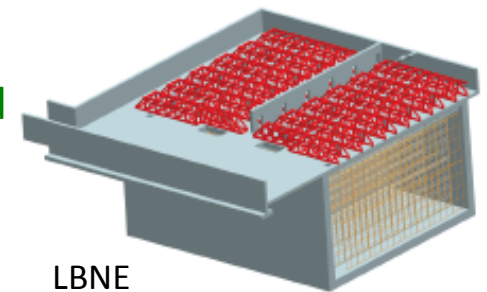
Cosmic Frontier Common Technologies

- Cryogenic detectors :
 - For CMB, Dark Matter and Dark Energy the new directions involve superconductor detectors such as Transition Edge Sensors or Microwave Kinetic Inductance Detectors in large arrays
- SiPM Arrays:
 - Dark Matter, gamma ray, UHE-CR experiments want large arrays of SiPMs (photodetectors).
 - Need large arrays, with low power readout and high bandwidth DAQ.
- ASICs:
 - In many cases these experiments also involve large channel count, with stringent power and density requirements. ASICs can address these issues



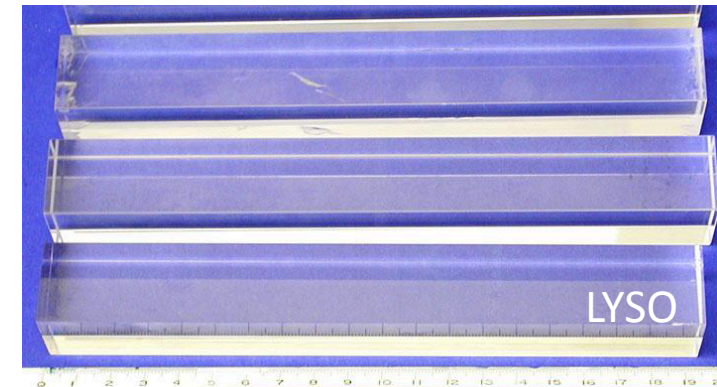
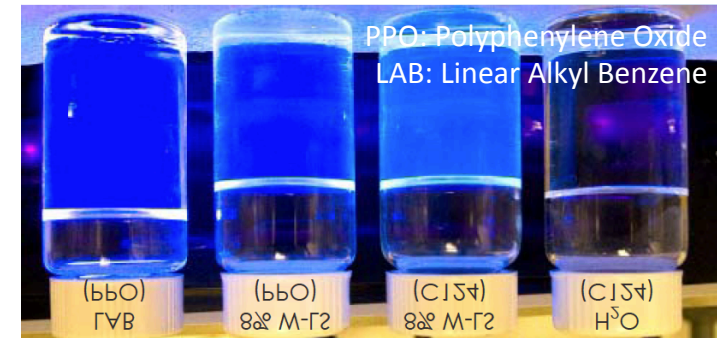
Intensity Frontier Challenges

- Neutrino Detectors
 - Large mass detectors required for neutrino detection and proton decay with cost-effective photon detection
- Rare Decay and Mu2e
 - R&D towards cost effective, high efficiency, fast EM calorimeters with good photon pointing and Time of Flight
- Rare Decay experiments and B-factories
 - Very low mass, high resolution, high-speed tracking for b, muon and kaon experiments
- Software for Rare Decay experiments
 - High fidelity simulation of low energy particle interaction
 - strategies to effectively simulate $>10^{12}$ particle decays &
- DAQ
 - High throughput, fault tolerant streaming data acquisition systems



Intensity Frontier Common Technologies

- Photodetection
 - Cost-effective, efficient photo-detectors permeates all detectors
 - Development of water-based scintillator materials
- EM Calorimetry
 - For kaon and muon experiments calorimeters with high efficiency photon detection, good photon pointing ($<20\text{mrad}$), Time of Flight ($<10\text{ps}$) and $<1\%$ energy resolution
- Tracking
 - Very low mass, high resolution, high-speed tracking for muon and kaon experiments: $0.001 X_0$ per space point, 100ps per track
- DAQ
 - Trigger-less system with high data volume (TB/second) throughput



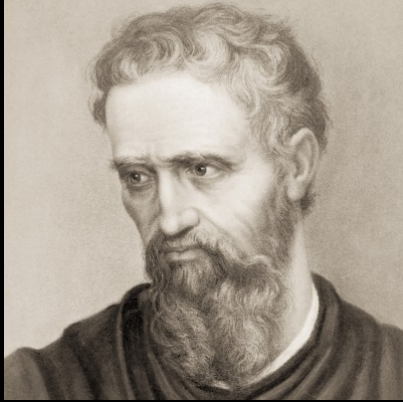
Strategic Themes

- From the plethora of technologies and needs of all the frontiers, identified key candidate areas for strategic investment that could form pillars of a future HEP program
- Criteria applied:
 - Hold promise of substantial cost saving
 - Hold promise of being breakthrough technology
 - If successful, should have enormous impact on the science reach
 - Based on the existing strengths and capabilities in the country
 - Preferably have impact in fields other than HEP

Summary Strategic Themes

Instrumentation Area	Possible Technology	Energy F.	Intensity F.	Cosmic F.	Nucl. Phys.	BES	Applied
Photodetectors	LAPPD or SiPM	✓	✓	✓	✓	✓	✓
Spectral Sensitive Pixels	MKID or Tiered Silicon			✓		✓	✓
Calorimetry	Crystal EM calorimetry, compensating	✓	✓		✓	✓	
Low Background Techniques	Neutron veto detectors Photodetectors, materials			✓	✓		✓
Intelligent Tracking	3D Silicon	✓	✓		✓		
Custom Electronics	Waveform sampling ASIC Cold electronics	✓	✓	✓	✓	✓	✓
Low-mass tracking	Carbon, G-pixel Si, power delivery	✓	✓		✓		
DAQ	ATCA, high-speed optical links	✓	✓	✓	✓		
	... more this week ...						





"The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark"

-- *Michelangelo*

"Nobody remembers number 2"

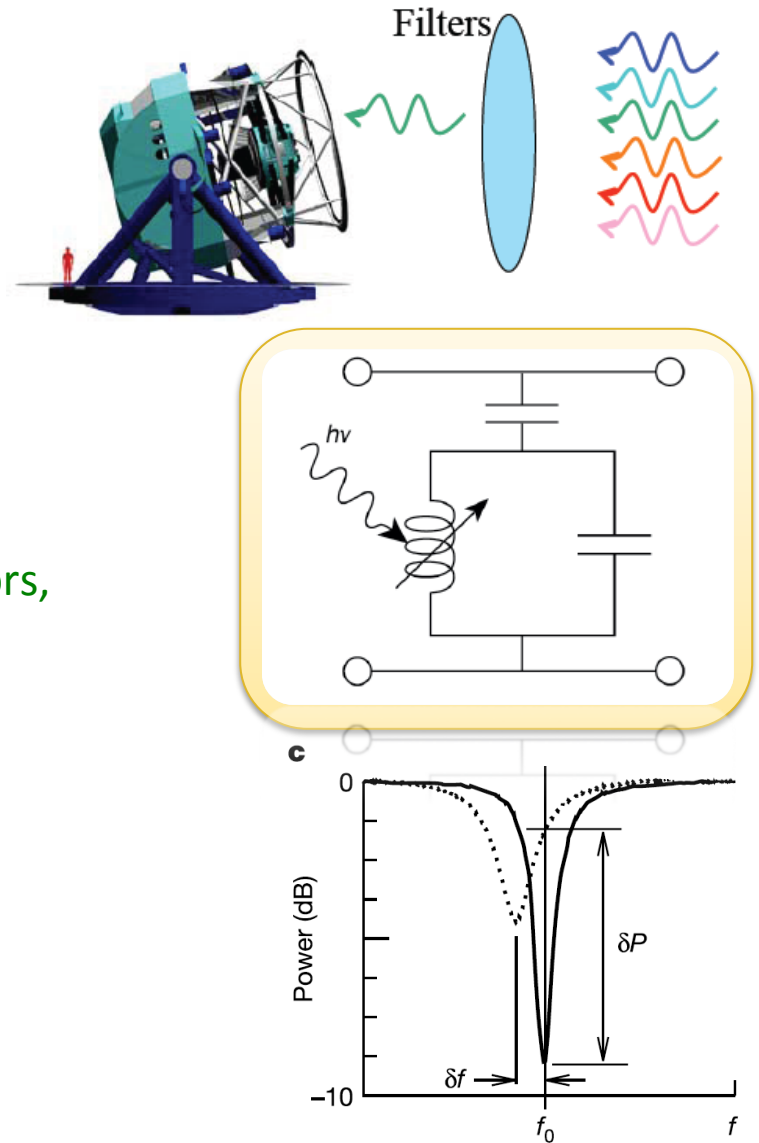
-- *Sam Ting*

Backup stuff



Why Spectral Sensitive Sensors ?

- Wide-area optical surveys for cosmology use filters, which is an untenable proposition for the future
- Determination of Photo-Z is critical for addressing many questions in cosmology
- The US is a leader in this area of science !
- A new technology, Kinetic Inductance Detectors, could address this issue and would be truly transformational.
 - The kinetic inductance of the superconducting strip is inversely proportional to the density of Cooper pairs and thus the color of the photon
- Development of this technology would have a tremendous value to today's cosmology



Role of Instrumentation

- ✓ For existing experiments, such as LHC experiments, preservation of Knowledge and Technical Expertise
- ✓ The best way to preserve/create knowledge and expertise is to have ongoing construction projects (our projects are usually challenging)
- ✓ In-house technical expertise – at Laboratories and Universities – is indispensable and vital in the successful delivery of large system
- ✓ Instrumentation allows young people to get involved in projects that may be more than a decade away from realization.
- ✓ Investment in instrumentation can allow us to keep a leadership role in the science when flagship facilities are offshore.
- ✓ The goal of instrumentation is not only incremental improvements of existing technology, but the development of new cost-effective transformative technologies; the emphasis is on innovation
- ✓ Track technologies and combine the advances in all areas of science and applying them to address prominent scientific questions: multi-disciplinary approach
- ✓ Break the isolation and export our key successes to other areas of science and to society at large through technology transfer to industry

